URBAN TRAFFIC CONTROL SYSTEMS SPECIFICS AND ARCHITECTURES

Ana Maria Nicoleta MOCOFAN[1], Răzvan GHIȚĂ[2], Iulian BĂȚROȘ[3]

The Urban Traffic Control systems (UTC), as Intelligent Transportation Systems (ITS), went through a continuously transformation and development process during the past decades, all in the context of defining a logical platform based on the traffic developers' needs for planning and integration of the Intelligent Transportation Systems. Based on this framework, we achieved a specific set of architectures for Urban Traffic Control systems that can be applied as a general starting platform needed within the planning, designing and implementing process of any kind of UTC system.

Keywords: architecture, platform, planning, traffic control

1. Introduction

The Urban Traffic Control systems (UTC) are a specialized form of management systems that coordinate traffic lights on a wide area, thus achieving an efficient flow control at a network level [1].

UTC systems represent a major area of our PhD research, therefore we are very much involved in studying their specifics, evolution and related activities, such as defining and applying UTC system architectures (framework) in performing study cases and developing certain parts of an UTC system, particularly related to communication methods and models. By creating a specific set of ITS architectures for UTC systems, we are aiming to help systems' developers in achieving efficient results by offering them a starting conceptual basis and allowing them to concentrate their energy in expanding each building block into more specific details.

This paper presents the UTC fundamentals and systems' architectures we created as a first step of our research, starting from a wider framework developed by the Federal Highway Administration of the United States, the so called

[1] PhD student, Depart. of Telecommands and Electronics in Transports, University POLITEHNICA of Bucharest, Romania, e-mail: nicoleta_mocofan@yahoo.com
[2] PhD student, Depart. of Telecommands and Electronics in Transports, University POLITEHNICA of Bucharest, Romania, e-mail: razvan_ghita_its@yahoo.com
[3] PhD student, Depart. of Telecommands and Electronics in Transports, University POLITEHNICA of Bucharest, Romania, e-mail: iulianbatros@gmail.com

“National ITS Architecture”, and it became the basis of all the UTC related work we have done ever since.

For documentation, we also used other manuals issued for the United States road traffic system, such as the latest update of the “Traffic control systems handbook”, as well as Professor’s Marius Minea of Transports Faculty inside University Politehnica of Bucharest book “Sisteme inteligente de transport - aplicații (Intelligent transportation systems – applications)”.

2. UTC systems fundamentals

According to the city’s size, the traffic request and particular cases in certain areas, the authorities can choose to implement a specific type of control system producing a desired level of optimization of the general traffic situation.

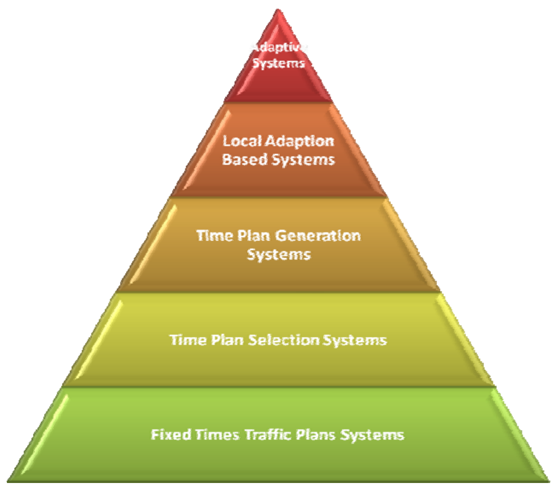

Fig. 1. Types of UTC systems

The evolution, in time, of the urban traffic control systems was the following [2]:

- *Fixed times traffic plans systems*

This has been the first step taken to offer automatic traffic control combined with increased safety measures. Even if it is the oldest method, many systems are still using it because of various reasons: the system’s modernization is not a priority or a necessity, the lack of financial resources, the area’s size and complexity. Any type of optimization is manual work, but the system’s designers have a certain freedom in deciding what best suites the junction’s context. They can implement lower cycle times or introduce additional phases in order to increase efficiency for the main movements.

The drawback is that fixed times plans cannot follow the changes in traffic and therefore will not automatically answer to incidents or variations that may affect the system's capacity.

- *Traffic plan selection systems*

These systems are based on the previous type, but they represent a first and huge step forward to intelligent traffic control. They are more cost intensive as for the first time, traffic detectors placed in the field are used for gathering traffic data, but less time consuming as the time plans are automatically computed and selected for each time interval of the day.

However, their benefits are not much better than those of the traditional fixed times plans, as they still do not respond to unexpected traffic changes or incidents.

- *Time plan generation systems*

These systems make better use of the data collected using the traffic detectors in the field by automatically processing this information and generating the signalling plans to be used in the next traffic cycles at periodic intervals. Unlike the first two types of systems, this one should be able to handle traffic variations and unexpected situations, even if the plans' processing and implementation does not happen in real time.

- *Local adaption based systems*

To make it even more efficient, this category of systems use the local adaption of traffic controllers to modify the initial fixed time plan implemented in a certain junction. The local controller can skip, terminate or extend a traffic phase according to the data collected in real time using the detectors strategically placed in the field.

- *Centralized adaptive systems*

This is one of the two types of fully adaptive traffic control systems available today. All the junctions within the system are linked through their signal controllers to a central computer placed in a traffic control centre. Having all the information available in a single place and in real time, plus the cutting-edge processing equipment in the data centre, bring along important benefits, such as the possibility of integrating the urban traffic control system with advanced incident detection systems, public transport prioritization systems or traffic information and guiding systems within a complex management system.

- *Distributed adaptive systems*

The second type of adaptive systems is not different in functions or capabilities than the centralized option; the main difference comes out of its communication architecture. Distributed systems do not use a central master computer, but use instead a full or partial mesh topology between the junctions' controllers (all the controllers in a certain area are linked to each other) and a routing module to direct traffic through intermediate nodes.

As mentioned before, this last type of system has major benefits for what concerns its main objective, of efficiently control the signals and produce good results within the traffic context in the area of implementation, but it also avoids the single point of failure issue of the centralized systems which produce a dependence between the central computer and the local points in the field.

Figure 1 summarizes the aforementioned UTC systems' evolution, with the newest solution (adaptive traffic control) on top of the pyramid.

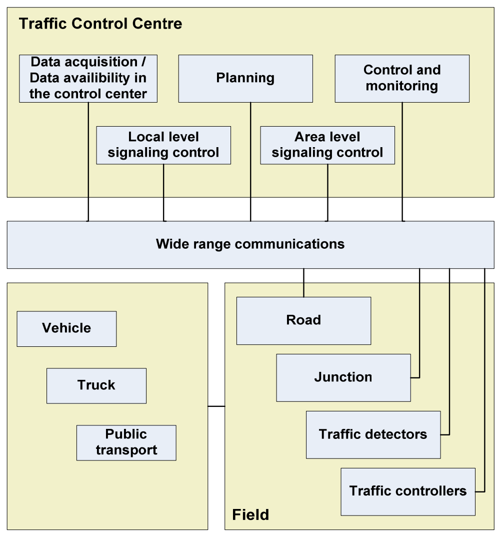

Fig. 2. UTC systems' block structure

UTC systems are usually made of a number of graphical display facilities, which offer a better understanding over the traffic situations in the controlled area. They include diagrams, queue creation and dispersion data, display of the individual operations in the junctions and diagrams of the travel distances, all meant to simplify the flow analysis inside the traffic control centre. Figure 2 displays the typical block structure of a modern UTC system, delimiting the main components that will be approached more in detail later in the paper. These are: the vehicle, the field elements, the control centre and the communication network.

3. UTC systems' benefits

UTC systems can be used for getting high traffic performance in a road network by reducing the vehicles' delays and unplanned stops [3].

Other main benefits of the UTC systems are:

- Balancing the network capacity by concentrating or redirecting the traffic from some areas or routes;
- Giving priority to emergency vehicles that need to intervene for different incidents and reducing waiting times by using special surveillance plans and key routes from the ambulatory stations or fire departments;
- Increased facilities for bikers and pedestrians;
- Reduction of delays caused by malfunctioning equipment by now using better monitoring and maintenance devices;
- Interaction with other traffic network management systems as well as with those of guidance and information on optimal routes.

4. ITS Architecture - concepts, definitions

An Intelligent Transportation System (ITS) architecture is a conceptual plan that defines the structure and/or the behaviour of an integrated ITS system. The architecture defines the system's components or its functional blocks and gives a basic view that can be used for developing the desired intelligent transportation system [4].

The ITS architecture defines:

- The specific functions of an ITS system (for instance the traffic data acquisition or the interrogations for obtaining the optimal route);
- The physical entities or subsystems that perform the system's functions;
- The information flow that interconnects and integrates these functions and physical subsystems into a system [4].

The analysis of the ITS architecture brings along other benefits within the planning and implementing of the ITS systems, including a usage schedule, an organizational point of view or risk and cost/benefits studies and analyses.

The ITS architecture is based on a set of functional requests that represent the users' needs indentified by actually consulting the users and the authorities within the transportation field. Therefore, it ensures that the system implementation will be adapted to the needs of all the involved parties and will not be created for innovation purposes only [5].

The development and implementation of the standardized ITS subsystems and components associated to the ITS architecture offers the possibility of an open market for hardware and software solutions, ensures data consistency, encourages the investments and helps to facilitate interoperability.

In the following sections, we will describe the UTC specific architectures we have developed and documented within our research, representing a starting point for any urban traffic control system, as well as for their gradually development and improvement (in time). By using this basic set of architectures created by the authors, traffic engineers working on conceiving new UTC systems for an urban area or entire city can benefit of a pre-defined layered plan meant to leverage their work and allow them to focus on technical and operational details.

An UTC system developed using the proposed architectures as a foundation can then be integrated within a larger Urban Traffic Management and Control System (UTMC) including other types of ITS systems such as public transport management, advanced traffic information systems, automatic incident detection, etc. The migration will go smoother if all these systems are built using the same conceptual plan: the ITS architectures [6].

UTC Physical Architecture

By sketching the physical architecture of an urban traffic control system in figure 3, we primarily defined its major elements, between which the logical links and the communication network for traffic data transmission are established.

The vehicle can be any type of automobile: small cars, trucks or public transportation fleet.

Traffic detectors gather data from junctions or road sections, providing the information needed in the control centre for performing the main functions of the system.

The detectors' selection is made according to the system's requirements, the functions performed at present - but taking into account the possible future developments, their precision, the location they are to be installed in and, of course, the available financial resources.

The traffic controller is a key element of the field physical subsystem because this is the level where the signalling plans based on the detectors' data are implemented.

Therefore, when a vehicle passes through a traffic detector's range, its presence is registered and, depending on the detector's technological capabilities and the settings made for satisfying the requirements in the control centre, a series of other information like volumes or speeds can be sent forward to make them available in the data centre.

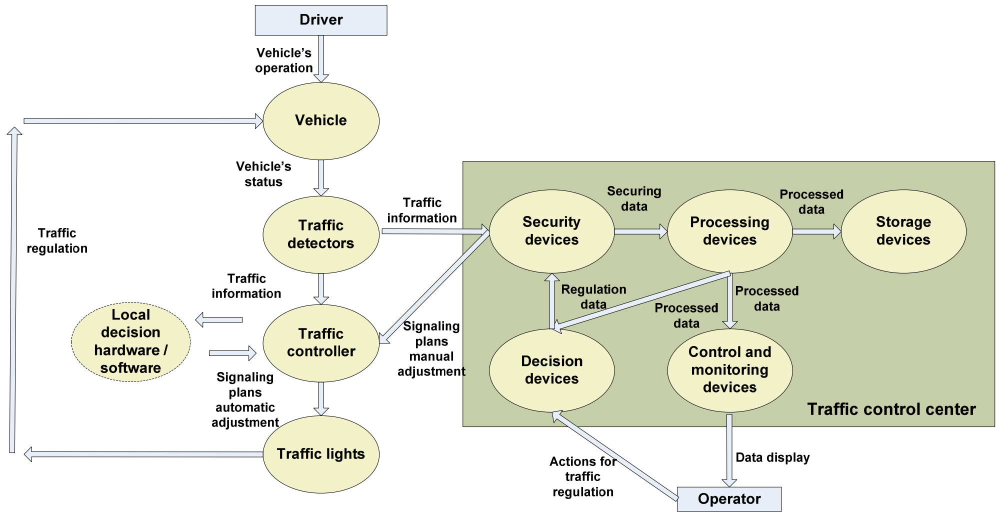

Fig. 3. UTC physical architecture

Next, the data related to the traffic volumes locally detected are routed to:

- The junction controller, that will use them to generate a signalling plan and automatically adjust the traffic in the field by locally implementing it (using micro-regulation decisions from the additional hardware or software modules attached to it);
- The control centre, where the data collected from the detectors can be primarily used for manual adjustment of the traffic signalling plan when needed and, as a second use, for incident detection and building traffic statistics.

At the control centre level, the detectors' data are first passed through a firewall, installed both for ensuring the integrity and confidentiality of data, and to prevent possible external attacks to the system. The data are then sent to the processing dedicated equipment, where they are converted into useful information, suited for the following hardware levels:

- Storage equipment, for historic data maintenance;
- Monitoring and control devices, used for displaying the junction's specific data on the screens in the control centre so that the human operators here can analyze them;
- Decision making equipment, where all the decisions for the macro-regulation of traffic are made.

The data for local or area based adjustment of traffic are passed through the security filters once more and then sent back to the controllers in the field in order to implement the appropriate signalling plan if needed.

UTC Logical (Functional) Architecture

We developed the proposed logical architecture of an urban traffic control system in order to describe the functions performed by the system at a detailed level.

The main functions accomplished by an urban traffic control system are coloured in red in figure 4, reflecting the UTC logical architecture. They are the high level functions of the system because they practically justify the purpose and usage of the system.

The most important functions of the system are performed at the traffic centre level, making it the central command and control point.

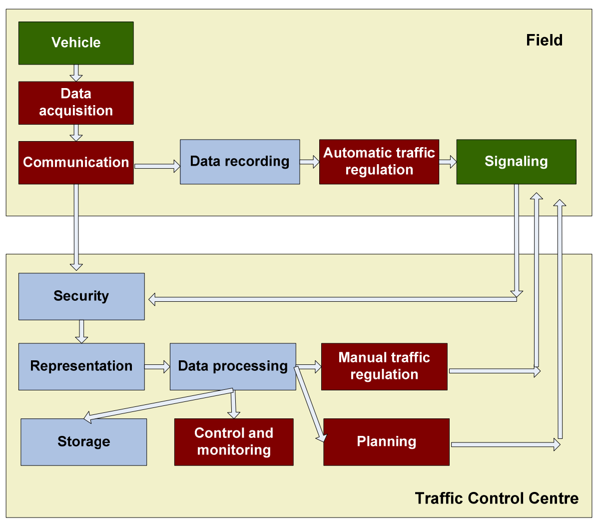

Fig. 4. UTC logical (functional) architecture

Among the high level functions performed at the traffic centre level, we can identify: acquisition/availability of traffic information from the field, planning, monitoring and traffic control, as well as the manual adjustment at a local and regional level of the system (the traffic operators can remotely apply changes to the program used by the controllers in the field for establishing signalling plans).

At the control centre's level, we are dealing with three high level functions previously mentioned:

- Traffic planning;

- Traffic monitoring and control;
- Manual traffic adjustment in case of emergencies or other special situations.

We can also identify some low level functions here, called like this because they do not make the main objective of the system; they represent intermediate steps in achieving results or high level functions that define the traffic control system. These low level functions are:

- Ensuring data security in order to avoid their corruption or system information leaking;
- Data representation to obtain a suitable format for the processing subsystems and for the graphical user interface (for the operators in the control centre);
- Data processing for using the information gathered from the field within the traffic monitoring and adjusting operations;
- Data storage for maintaining a history in time.

The high level functions in the field are:

- Data acquisition accomplished by the traffic detectors;
- Automatic adjustment of the junction traffic plan, accomplished by the local controller;
- Even if it does not lead to the UTC system's purpose defining, the communication between its components is a high level function; without it, the system's functioning would practically be impossible.

As a low level function, we can identify the recording of the traffic detectors' data by the controllers in the field, representing the foundation on which decisions for traffic signalling planning are made.

UTC Reference Architecture

The reference architecture of an urban traffic control system displayed in figure 5 comprises:

- The "human" component, represented by the drivers and the operators within the traffic control centre, as they are the most qualified for supervising and applying emergency measures when needed;
- The system's functions impacting this human component:
    - For what concerns the driver, we are talking about handling the vehicle and following the indications provided by the system for ensuring and maintaining traffic safety;

  - For the traffic operator we are getting back to the same high level functions mentioned above, which define the purpose of the system and interact with the elements in the field.
- The vehicle and other physical entities in the field.

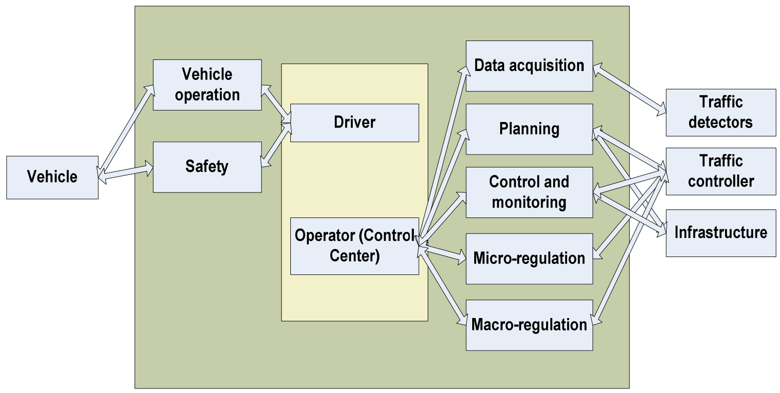

Fig. 5. UTC reference architecture

UTC Organizational Architecture

Within an urban traffic control system, the organizational architecture includes the institutions and parties involved in its development and implementation, from the lowest level, of one junction, to the highest, that of the entire city.

The organizational architecture in figure 6 is basically a geographical structure of the way the system was thought and establishes how the system should work at each of the identified levels.

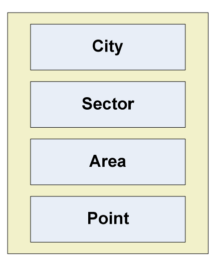

Fig. 6. UTC organizational architecture

UTC Communication Architecture

We propose the communication architecture in figure 7 for an urban traffic control system in order to describe the physical components of the system, at a detailed level of elements that are communicating with each other through data transmission networks based on international open standards, well defined and documented.

Thus, the three major entities (vehicle, field elements and traffic control centre) are interconnected through a wide area communication network, most likely working on fibre optic physical support.

The fibre optic is widely used within telecommunications, where it enables data transfer over large distances and at high levels of bandwidth, bigger than other communication media. They are mainly used instead of copper cables because they offer lower signal loss and are practically immune to electromagnetic interferences [7].

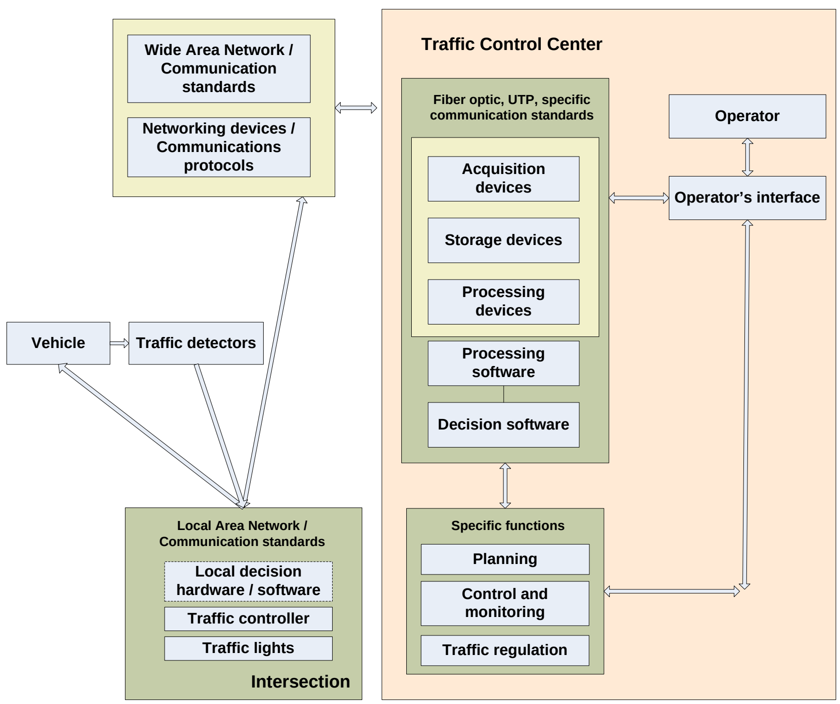

Fig. 7. UTC communication architecture

The traffic control centre is endowed with cutting edge equipment, with a high processing power, capable of working with big quantities of data. They run specific applications for performing all the functions defined by the logical architecture of an urban traffic control system and some allow the handling and monitoring using a friendly graphical user interface.

The equipment in the traffic control centre and those installed in the field are networking devices, meant for the physical interconnections of the junctions and for providing the linkage with the control centre, by managing the traffic data transfer using dedicated communication protocols.

6. Conclusions

The traffic engineers and system developers created the perfect framework for designing, planning and implementing intelligent transportation systems by defining a comprehensive platform able to provide the steps for the system's building, from a concept phase to its field deployment. This framework, called the ITS architecture, describes several standard point of views for any system about to be developed, that become specific for each and every intelligent transportation system type. New services or geographical deployments can be provided without expensive solutions or major adjustments of the existent systems, as long as the future developments are covered by the functional parameters defined by the architecture.

Based on the general ITS architecture studies and framework, we applied the specific concepts and knowledge and designed the UTC (Urban Traffic Control) systems set of architectures. They can be used within the planning and implementation phase of any kind of UTC system, as well as for future developments of existing ones.

Acknowledgements

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